A SEARCH FOR γ–RAY EMISSION FROM ACTIVE STARS

S. M. WHITE,
Dept. of Astronomy, Univ. of Maryland

B. A. HARMON,
USRA/Marshall Space Flight Center

J. LIM
Solar Astronomy, Caltech

& M. R. KUNDU,
Dept. of Astronomy, Univ. of Maryland

ABSTRACT γ–rays have not yet been detected from active stars, but based on the solar analogy and the high levels of solar-like activity they show, there is no doubt that these stars do produce hard X-rays and γ–rays, which might constitute a significant fraction of the observed low–energy galactic γ–ray background. However, the sensitivity of current detectors makes detection difficult. Here we report on an ongoing attempt to detect several active stars using the Earth-occultation technique and the large-area detectors of the BATSE instrument on the *Compton Gamma Ray Observatory*.

WHY SHOULD ACTIVE STARS PRODUCE HARD X–RAYS/γ–RAYS?

• Well, even the Sun, that feeble (by the standards of RS CVns and flare stars) orb, produces them at a respectable level, although only during flares. It produces soft X-rays all the time.

• Active stars produce copious amounts of soft X-rays during flares, and there is no reason to assume that there is a high-energy cutoff in the spectrum.

• Active stars also produce nonthermal radio emission all the time, which requires the presence of >500 keV electrons in the corona. Thus the electrons required to produce hard X-rays and γ–rays are certainly there, even outside of flares. So we know that the energy spectrum does not have a high-energy cutoff that would prevent stars from producing hard X-rays.

WHY DO WE CARE?

• There is observed to be a diffuse galactic γ–ray background, which could well have a significant component contributed by active stars. The high-energy component is almost certainly due to the interactions of cosmic rays with molecular clouds, but the low-energy component could have different sources. There are $\sim 10^{10}$ M dwarf flare stars and possibly $\sim 10^{9}$ active close binary systems such as RS CVns, so it would only take small mean fluxes from each to produce a substantial total contribution.

• In solar flares the hard X-rays are a diagnostic of the primary energy release in the flare, which is thought primarily to accelerate electrons to energies of 10–100 keV. These electrons then strike the solar chromosphere and heat material there up to temperatures of order 10^{7} K, which produces the observed soft X-rays from flares. Thus in solar flares the hard X-rays are to the soft X-rays as the dog is to its wagging tail. *Are we in stellar X-ray astronomy only studying the wagging tail and missing the dog?*

• It seems likely that the hard X-rays from stellar flares will be a lot more interesting than the soft X-rays; on the other hand, perhaps stellar flares are quite different and produce relatively weak hard X-rays. We will never know until we detect them.

PREDICTED FLUXES OF HARD X-RAYS/γ–RAYS

The most sensitive hard X-ray/γ–ray detectors ever flown are presently aloft on the *Compton Gamma Ray Observatory*. A number of us in the stellar community have tried to persuade GRO that active stars are a target worthy of some Guest Investigator support, so far without success. The problem is that active stars have never been detected at these energies, so we have a hard time convincing them that we will see enough photons to make it worthwhile.

There are a number of ways to predict the fluxes you might see, e.g., you could start with the known soft X-ray fluxes and extrapolate to higher energies. We have started from the other end: we have used the known levels of quiescent nonthermal radio emission, which is a diagnostic of mildly relativistic electrons, and assumed that the energy spectrum of the radiating electrons extends down to 25 keV. If you do this, you get the following approximate formula relating the differential photon flux at an energy E to the observed level of radio emission in milliJansky, S_{mJy}:

$$\frac{dJ}{dE}(E) = 10^{-11.61+1.83\delta}\,\frac{S_{mJy}}{\tau_3}\,\left(\frac{B}{50\,G}\right)^{0.22-0.90\delta}(\delta-1)\left(\frac{E}{25\,keV}\right)^{-\delta} \quad \text{photons cm}^{-2}\,\text{s}^{-1}\,\text{keV}^{-1} \tag{1}$$

The quantities in this equation which are not measured are the magnetic field in the radio source, B; the energy spectral index of the radiating electrons, δ; and the typical lifetime of an electron in the corona before it strikes the chromosphere and produces a hard bremsstrahlung photon, τ_3 (in units of 10^{3} seconds). *δ is the most important of the unknowns*: the radio flux is really a measure of the numbers of the > 1 MeV electrons, whereas the hard X-rays are produced by the 50 keV electrons. The larger δ is (i.e., the steeper the energy spectrum), the more 50 keV electrons you have for a given radio flux and therefore the more hard photons detectable by GRO you will get (also, smaller B gives you more hard X-rays).

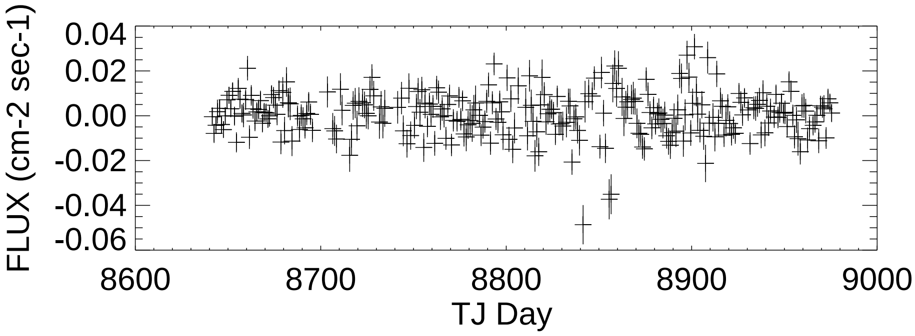

FIGURE I Daily averaged values of occultation fluxes for HR 1099 in the photon energy range 30 – 1800 keV.

Since most of the detectors on GRO have poor spatial resolution, the best way to try to detect stellar sources reliably seems to be by looking for Earth occultations of candidates by the 8 large–area (2000 cm^2) detectors of the BATSE instrument. There are about 16 such occultations per day, and BATSE has a list of about 40 sources, such as Cyg X-3 and the Vela pulsar, whose occultations it routinely monitors. For the lowest energy range of BATSE (25 – 50 keV) we predict the following photon fluxes (in photons cm^{-2} s^{-1} kev^{-1}) for two values of δ and a "typical" magnetic field of 50 G: 3.3 $\times 10^{-3} S_{mJy}/\tau_3$ for $\delta = 5$, and 5.6 $\times 10^{-7} S_{mJy}/\tau_3$ for $\delta = 3$. Fishman *et al.* (1989, *1st GRO Science Wkshp.*) quote a 1-day (16 orbit) sensitivity of 1×10^{-4} photons s^{-1} cm^{-2} keV^{-1}. So for a moderate radio flux of 100 mJy an RS CVn may well be detectable provided the electron energy spectrum is steep enough (in fact, our last proposal was criticised because these numbers could make a stellar source as bright as the Crab under the right conditions; this was deemed ridiculous, apparently). The flux calculated above represents steady emission; there is also probably a very intense, short-timescale hard X-ray flux associated with flares.

As a trial, 3 active stars have been added to the list of objects monitored by BATSE. To be consistent with the above argument, they were chosen on the basis of frequent large radio outbursts, although they are natural candidates on virtually any basis: HR 1099, AR Lac (both RS CVns) and HD 32918 (a southern FK Comae star). While M dwarfs are the most numerous active (and radio) stars, their radio fluxes are generally weak compared with RS CVns and it will probably be more difficult to detect them as γ–ray sources.

An example of the data is shown in Fig. 1. So far we have no unequivocal detections, but we expect that at some point GRO will detect an active star and (hopefully) open up a new area of stellar research. The observations continue and a more thorough analysis will be carried out shortly, including correlations with other activity diagnostics for these stars.

Research in stellar radiophysics at the University of Maryland is supported by NSF grant AST 92–17891.